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Rand/ARPA Climate Dynamics Research: Executive Summary and Final Report

W. L. Gates

A Report prepared for

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Rand
SANTA MONICA, CA. 90406

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Briefly reviews the research output of the Dynamics of Climate Project from 1969 to 1975. An overview of the project's principal research activities is given, including its significant accomplishments in the areas of atmospheric and oceanic modeling, climatic experimentation and analysis, assembly of climatic data, and programming and the use of the Illiac-IV computer. A bibliography of project publications is included. (BG)

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PREFACE

This report briefly summarizes the research output of the Dynamics of Climate Project, sponsored by the Defense Advanced Research Projects Agency (ARPA) at The Rand Corporation over the period 1969-1975. A bibliography of project publications is included as an appendix.

SUMMARY

The history of the Rand/ARPA Dynamics of Climate Project is briefly reviewed, and an overview is given of the project's principal research activities, including significant accomplishments in the areas of atmospheric and oceanic modeling, climatic experimentation and analysis, assembly of climatic data, and programming and use of the Illiac-IV computer. A preliminary assessment is made of future research needs.

ACKNOWLEDGMENTS

In the seven years during which intensive climatic research was conducted under ARPA sponsorship at Rand, many persons contributed to the success of the project's scientific and computational efforts. During its earlier years, the effort was directed by R. R. Rapp; his contributions, along with those of E. S. Batten, M. Warshaw, L. R. Koenig, and C. Schutz, are gratefully acknowledged.

I would also like to acknowledge the efforts over the past several years of M. E. Schlesinger and Jeong-Woo Kim in the development and analysis of the atmospheric and oceanic models; the skills of R. L. Mobley, D. S. Pass, and C. R. Huber in the programming and operation of the models and associated programs; and the administrative support provided by V. Pickelsimer. Thanks are also due the ARPA Information Processing Techniques Office for its generous and farsighted support under contract DAHC15-73-C-0181, including access to the Illiac-IV and IBM 360-91 computers through the ARPANET.

CONTENTS

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I. INTRODUCTION

The problem of climate--in particular the threat posed by possible variations in climate due to either natural or man-made causes--is one of the outstanding unsolved problems in geophysics. In spite of the accumulating store of conventional climatic data, and the more recent data from aerological and satellite sounding systems, many events of great climatic importance are poorly observed, especially those occurring over the oceans and in the Southern Hemisphere. A solution of the climate problem on the basis of a comprehensive physical theory of climate (or the definition of the limits within which a solution is possible) could be immensely valuable to man's agricultural and commercial activities, permitting rational development and allocation of resources for the future. This was clearly acknowledged by ARPA in its decision to initiate a comprehensive research program on climate in 1969.

Because the scientific study of climate and climatic change--i.e., climate dynamics--now includes not only the atmosphere but also the world's oceans, ice masses, and land surfaces (National Academy of Sciences, 1975; World Meteorological Organization/International Council of Scientific Unions, 1975), the complex interactions (or feedback processes) among these components of the climatic system are becoming better understood (Gates, 1975). Most modeling to date has focused on the atmosphere, but an increasing number of empirical and diagnostic studies are being made of atmospheric, marine, and geological records (Gates and Imbrie, 1975). A thorough understanding of the system, however, will require climate dynamics research to consider behavior of the *coupled* atmosphere-ocean-ice-land surface system. Another fundamental part of climatic research is the assessment of the inherent predictability of climate, which will require an extensive program of modeling by a variety of approaches, together with the analysis of both simulated and observed climatic data (Gates, 1976).

Although initially directed to more specific problems (see Sec. II), the Rand/ARPA climate research efforts have contributed to an increased understanding of the general climate problem. The cumulative work of the research project* shows that attention has been given not only to the development and application of both atmospheric and ocean models, but to the related questions of simulation analysis from physical, statistical, and synoptic viewpoints, and to the assembly of the climatic data necessary for testing and verification purposes. With the support contributed in recent years by the National Science Foundation, the project has been able to increase its cooperation with others in the climatic research community, and an increasing proportion of its research has recently been published in conventional scientific journals.

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*See the Appendix for a list of publications prepared by the staff of the Climate Project.

II. EVOLUTION AND HISTORY OF RAND/ARPA CLIMATE RESEARCH

At its inception in 1969, the Rand/ARPA climate research effort had three initial objectives:

1. To perform a series of global climate change experiments using numerical models.
2. To assess the international capability in the area of climate change research.
3. To design actions that might be taken to offset any possible future deleterious climatic changes (Rapp, 1970).

During 1969 and 1970, it became clear that such research could not be satisfactorily performed without access to, and a thorough familiarity with, at least one atmospheric general circulation model. The two-level model then under development at the University of California, Los Angeles, was identified as the simplest suitable model, and it was made available to Rand through Professors Y. Mintz and A. Arakawa of the UCLA Department of Meteorology. A comprehensive documentation of this model (Gates et al., 1971) served as the basis of our subsequent atmospheric modeling efforts.

Because a substantial and long-term commitment of resources was required to undertake the desired research, the Rand Dynamics of Climate project was established, with subprojects devoted to (1) atmospheric modeling and experimentation, (2) ocean modeling, (3) atmospheric turbidity, (4) cloud-scale circulations and cloud physics, and (5) numerical methods. Of these, the first two proved to be especially viable efforts, although the model development and testing were more difficult than expected.

From 1971 to 1972 primary attention was given to the production and analysis of a reference or control simulation with a refurbished version of the two-level model, and the systematic comparison of the simulated climate with the observed climate (Gates, 1972a). This work confirmed the overall capability of the model to simulate many of the principal features of global climate; it also identified a number of model shortcomings. Further insight into the physical fidelity of the basic model was given by an analysis of the simulated radiation and heat budgets (Kahle and Haurwitz, 1973) and by an analysis of the atmospheric forcing functions (Gates, 1972b).

Based on this experience, and using the basic experiment as a control, a number of preliminary climatic experiments were performed with the atmospheric model from 1972 to 1974 to examine the climatic effects of deliberate changes in the boundary conditions. These concerned

- Alterations in the extent of the Arctic sea ice (Warshaw and Rapp, 1972; Fletcher et al., 1972).
- The presence of anomalously high sea-surface temperatures.
- The reduction of solar radiation by stratospheric dust (Kahle and Deirmendjian, 1973; Batten, 1974).
- The presence of excessive condensation nuclei (Koenig, 1974).
- The presence of an artificial lake (Rapp and Warshaw, 1974).

Although these experiments simulated only 60 days' time under conditions of a fixed (January) sea-surface temperature distribution, they were sufficient to show that the model responded to changed boundary conditions in the generally expected manner. The detailed physical interpretation of the results, however, was handicapped by several deficiencies of the model. In particular, it persistently simulated too much precipitation and too little cloudiness, and made systematic errors in simulated low-level wind and temperature. Preliminary efforts to address these problems (Bhumralkar, 1974) indicated that the treatment of the planetary boundary layer and the hydrologic cycle (especially those elements concerned with convective processes) needed extensive revision.

In general, in such experiments the simulated climatic response to changed boundary conditions on monthly time scales is masked to a large extent by seemingly irregular differences with respect to the control in the simulated daily progression of the circulation. These differences result from the inevitable growth of initially small differences in the solutions, and the essentially unpredictable behavior of the synoptic-scale disturbances beyond a few weeks' time. In climate change experiments with such models, the problem of determining the statistical significance of the simulated climatic changes against this background of climatic "noise" must be resolved. Warshaw and Rapp (1972) first devised a statistical technique for attacking this problem, and on that basis the results of several experiments were judged to be significant. Further experimentation and analysis, however, were clearly necessary before definitive conclusions could be reached.

The potential importance of the oceans in climatic processes prompted the development of a baroclinic model of ocean circulation during the period 1972-1974 (Alexander, 1973), based on earlier experience with a homogeneous oceanic model (Gates, 1970). Although of relatively coarse resolution and shallow vertical extent, this model portrayed many large-scale features of the observed surface circulation when subjected to realistic surface wind stress and heating. Later experiments with the model over seasonal time scales, however, indicated that simulation of sea-surface temperature--the most important oceanic variable for the purposes of climate--needed to be improved and that ocean bottom topography must be considered before such models could be usefully coupled to their atmospheric counterparts on climatic time scales.

The need for accessible and concise information on the observed global distribution of climate, especially on those variables included in the atmospheric and oceanic models, was recognized early in the research. From 1971 to 1974 considerable effort went into collecting seasonal climatological data sets for the principal atmospheric variables (Schutz and Gates, 1971, 1972a,b, 1973a,b, 1974a,b) and for the monthly distributions of sea-surface temperature and sea ice (Alexander and Mobley, 1974). Since these data were processed and displayed in a model-compatible format, they proved of great value in model calibration and in verification of the simulated climate. A similar tabulation was also made of the global distribution of terrain height and ocean depth (Gates and Nelson, 1973a,b, 1975a,b) to permit the objective determination of surface boundary conditions.

Although this research clarified several aspects of the problem of climate dynamics, it also indicated a need for further basic research and model experimentation before clear answers could be expected to the many questions surrounding possible man-made climatic changes. To this end, the Rand Climate Project was established in 1974, and attention was restricted to the first of the three initial objectives: to perform a series of global climate change experiments using numerical methods. In this current phase of the effort, research has been intensified on selected aspects of the modeling and experiment analysis problems, and on efforts to use the Illiac-IV computer and ARPANET facilities in the most efficient manner. An overview of these efforts, several of which are continuing under NSF sponsorship, is given in Sec. III.

III. CURRENT RESEARCH OVERVIEW

ATMOSPHERIC MODELING

The principal vehicle of climatic research is an accurate and efficient model of the global atmosphere. To evaluate the characteristic errors of the atmospheric model used at the outset of the study, during the period 1974 to 1976 the simulated January and July global climate was systematically compared with the observed climate. The model's performance is illustrated in Fig. 1, which compares the simulated July sea-level pressure with climatological observations. Although not shown in this figure, the model's major errors were associated with simulation of excessive convective precipitation in the lower latitudes, simulation of too little total cloudiness, and simulation of excessive strength of the quasi-stationary planetary-scale waves in middle latitudes.

In an effort to correct these errors, a major revision of the two-level atmospheric model was begun in 1974 by M. E. Schlesinger and is now nearing completion. Along with changes in the treatment of radiation, convection, and cloudiness, moisture has been introduced into the previously dry upper model layer, and surface snow cover has been introduced as a predicted variable. In preliminary tests, the new model is substantially more accurate than its predecessor in simulation of the momentum, heat, and hydrologic balances, and new seasonal control simulations now under way will be completed under NSF sponsorship. Some of the model's computational procedures have also been revised, and the new version is approximately twice as efficient as the previous one.

CLIMATIC EXPERIMENTS

The only climatic experiment made since the completion of the earlier series is one that simulated the July climate of the last ice age (approximately 18,000 years ago) (Gates, 1976a). In this experiment the revised model was used with the ice-age boundary conditions assembled by CLIMAP (1976). The simulated ice-age July sea-level pressure is shown in Fig. 2. As anticipated, the ice-age July climate was both colder and drier than today's July climate, especially over the

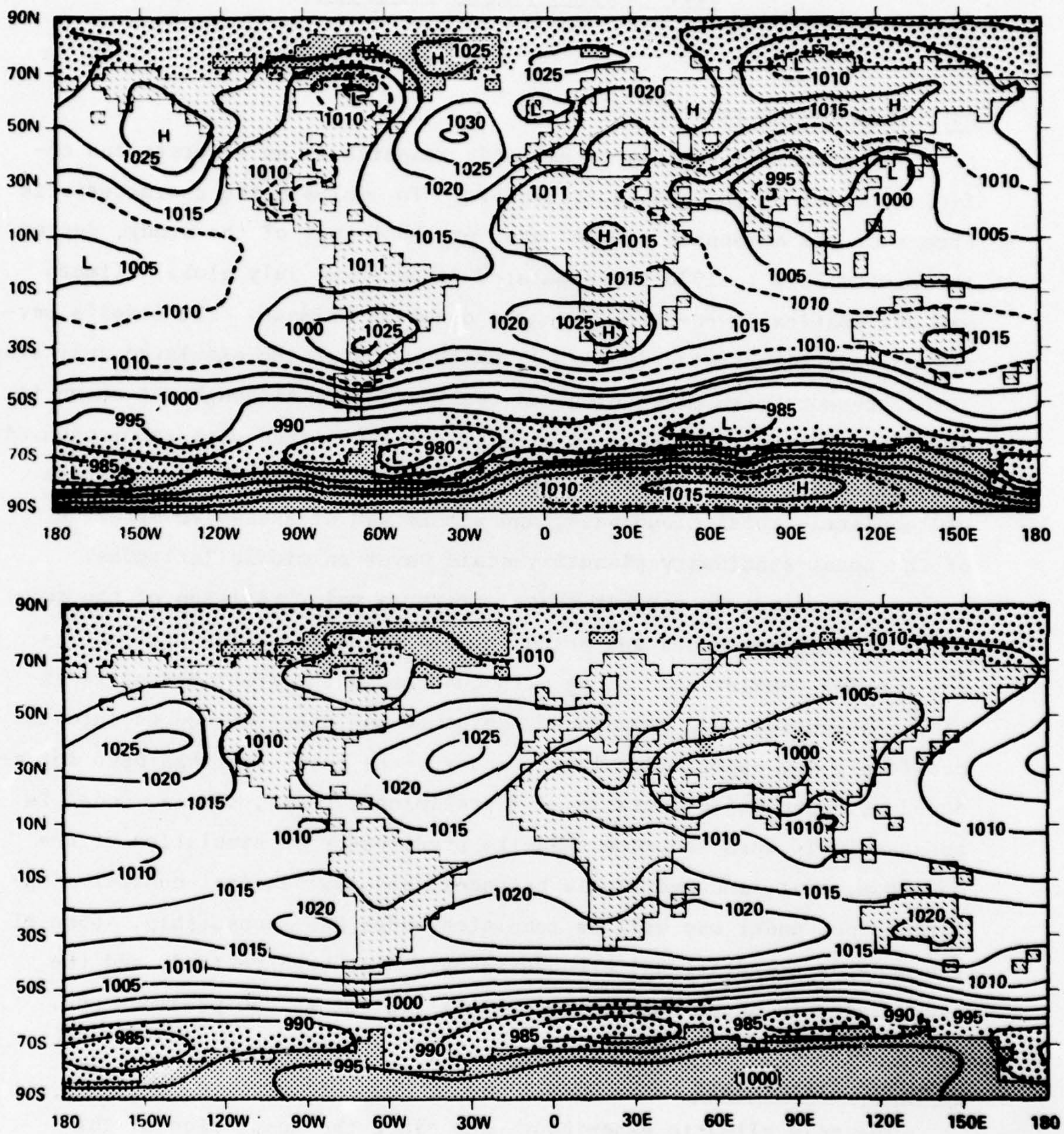

Fig. 1--The global distribution of July sea-level pressure simulated by the two-level model (above) and that given by climatological observations (below). The isobars are labeled in mb, and the assigned distribution of sea ice and of ice- or snow-covered land is indicated by the large and small dotted patterns, respectively, with cross-hatching denoting bare-land continental areas as resolved by the model's computational grid (from Gates and Schlesinger, 1976).

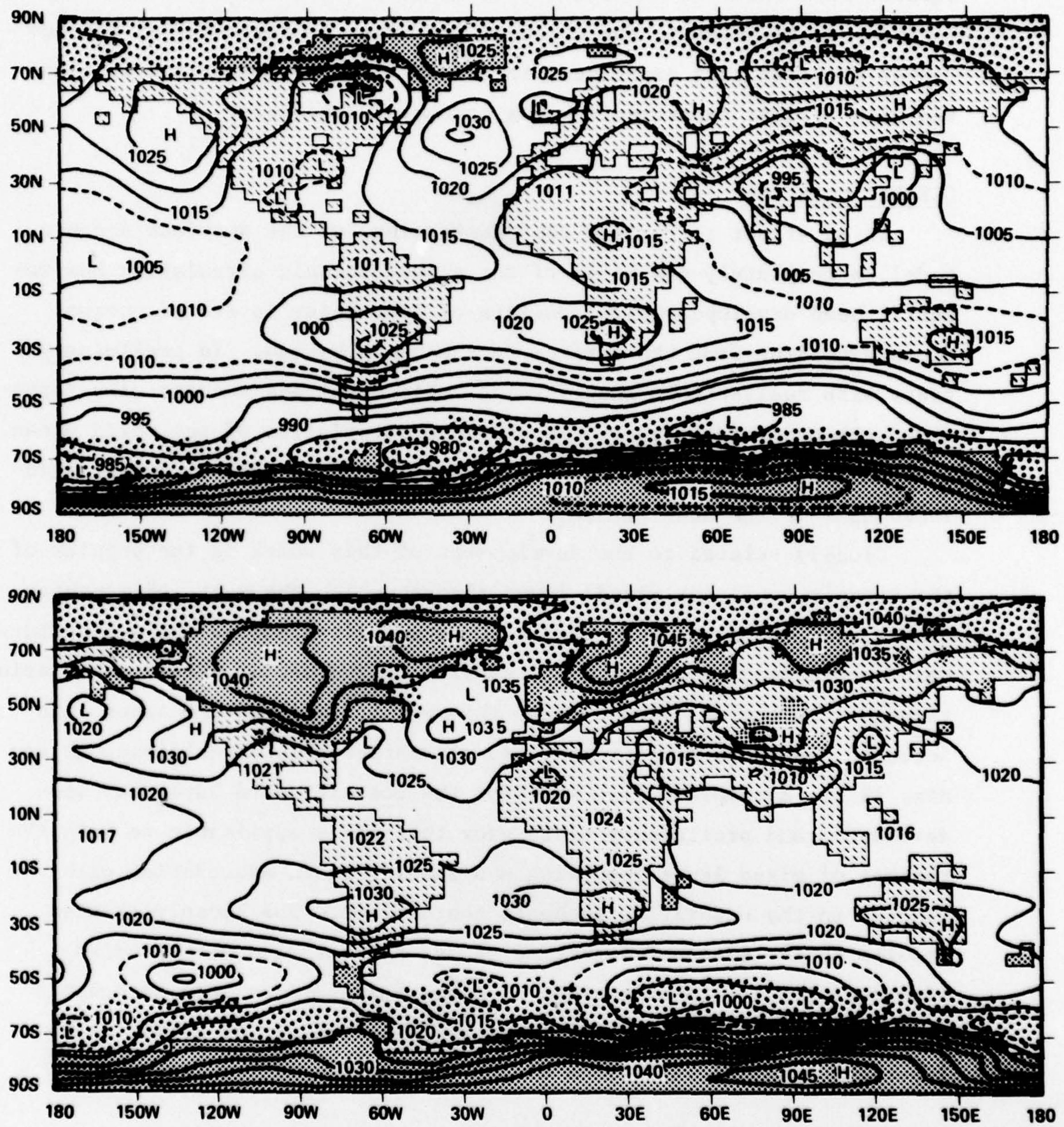

Fig. 2--The global distribution of July sea-level pressure simulated by the two-level model for conditions of the last ice age of 18,000 years ago (below) and that simulated for present conditions (above; see also Fig. 1). Note the extension of land- and sea-ice during the ice age, and the slightly altered continental outline due to the ice-age lowering of sea level (from Gates, 1976a).

continents of the northern hemisphere. There was also a pronounced equator-ward shift of the zones of maximum zonal circulation and eddy activity in response to the expanded ice cover. Gates (1976c) has recently analyzed this experiment in detail; further comparison is planned with similar experiments being conducted elsewhere.

OCEANIC MODELING

In an effort to correct the shortcomings of the previous oceanic model, a completely new model of the global oceanic circulation has recently been developed which consists of four water layers of unequal depth extending from the surface to the ocean bottom. In preliminary tests with realistic surface forcing, this model has successfully reproduced the major features of the observed circulation of the world ocean. Seasonal circulation regimes will be examined over several years' simulated time in the near future.

Closely related to the development of this model is the problem of the ocean's upper (or mixed) layer through which the heat and momentum fluxes from the atmosphere pass. To accurately simulate the sea-surface temperature (and hence the heat transfer to the deeper water), the variations of the thermal structure of this mixed layer must be taken into account. Based on earlier analyses of weather ship data (Alexander and Kim, 1975), a comprehensive model of the oceanic mixed layer has been developed, and preliminary tests show that it is applicable to both the regimes of mixed layer deepening and shallowing in association with changes in the underlying seasonal thermocline. The closely related problem of the seasonal formation of sea ice has also been studied (Semtner, 1976). Incorporation of these formulations into an oceanic general circulation model will permit simulation of the climatically important seasonal variations of the sea-surface temperature.

ANALYSIS METHODS

As previously noted, the determination of the statistical significance of supposed climatic changes simulated by numerical models is an important aspect of climatic research. Using the concepts of climatic noise developed earlier, a comprehensive analysis of this problem has recently been completed (Laurmann and Gates, 1975), which allows estimation of the amount of experimentation (or number of trials) necessary to establish statistical significance. This study also takes into account the possibility that both the mean and the variance may be different in a climatic experiment from what they are in the corresponding control. This is a generalization of the approach recently taken by Chervin et al. (1974) and Chervin and Schneider (1976).

The transports of momentum and heat simulated by the mean meridional circulation and by the stationary and transient zonal eddies have also been analyzed. This analysis reveals much about the basic mechanics of atmospheric circulation, and indicates, for example, that the model tends to overestimate the transports made by the stationary eddies as compared with observation, while underestimating those effected by the transient eddies. These effects, along with the model's simulated energetics, are being studied further.

PROGRAMMING AND COMPUTATION

A significant portion of the Rand research effort has always gone into the design and execution of computer programs for remote execution over the ARPANET. These include not only the primary atmospheric and oceanic simulation codes themselves, but a variety of auxiliary programs for the analysis and display of the results. Built on previously completed work (Pass, 1974; Cooper et al., 1974), programs are now available for the automatic global contouring, display, and averaging of both primary and secondary modeled variables, and for the calculation of selected covariances and other statistics. These routines, which are in almost continual use, form an important part of the program's overall efforts.

A major computational goal of the program has recently been achieved in the successful check-out and execution of a version of the new atmospheric model on the Illiac-IV computer. Using a code written in IVTRAN (replacing an earlier version written in GLYPNIR), the model simulates one day of atmospheric time in approximately 2.5 min on the Illiac-IV, which is about three times faster than the IBM 360-91 for this problem. This speed may be increased even further with future changes in the Illiac-IV system and the provision of a mass storage device. Only with a machine of this class can we realistically envisage integrations of the atmospheric model over the climatically important interannual time scales.

IV. SUMMARY OF SIGNIFICANT ACCOMPLISHMENTS

Although it is difficult to judge the value of research at short range, perhaps the best measure of the project's success is that it has been accepted as part of the national and international climatic research community. Aside from the solution of specific problems in climate dynamics, a number of the project's more general accomplishments have advanced the overall state of the art. These contributions include the following:

- The preparation of a comprehensive documentation of an atmospheric general circulation model.
- The identification (and at least partial correction) of model errors by a systematic comparison of the seasonal performance of a sequence of atmospheric models against observation.
- The demonstration that a two-level atmospheric general circulation model can successfully simulate many features of the observed seasonal climate, although care must be taken in the treatment of the surface boundary layer, convection, and cloudiness.
- The demonstration that the simulations produced by general circulation models over shorter-period climatic time scales (i.e., months and seasons) contain a noise component of relatively large amplitude which is physically unrelated to the conditions of the experiment, and that a statistical analysis is required in most cases to isolate a significant climatic signal.
- The assembly of a comprehensive body of observed climatic data in a uniform and model-compatible format.
- The demonstration that general circulation models can be successfully executed in extended integration over remote data links such as the ARPANET, and that systems such as the Illiac-IV are capable of use in such research.

- o The demonstration that climate dynamics research requires coordinated and sustained effort in theoretical and modeling studies, the physical and statistical analysis of simulated and observed climatic data, and adequate programming and computational support.
- o The conclusion that further progress in understanding climate and climatic change will require study of the response and sensitivity of a hierarchy of models, improved parameterizations of the many physical processes involved in the maintenance of climate, and the construction of viable models of the coupled atmosphere-ocean-ice-land surface system.

Appendix

PUBLICATIONS LIST OF THE RAND/ARPA CLIMATE DYNAMICS PROJECT

Listed here by author are the various Rand reports and papers prepared by the staff of the Climate Project since its inception in 1969. Many of the reports have been (or will be) published in the scientific literature in either the original or revised form. Some papers written specifically for external journal publication were not given a Rand report identification, and so are not included here. Thirty-six unpublished working notes are also not included.

Alexander, R. C., *Studies in Climate Dynamics for Environmental Security: A Calibrated Analytical Model for the Thermohaline and Wind-driven Circulation in the Interior of the Subtropical Ocean*, R-505-ARPA, September 1970, 33 pp.

Alexander, R. C., *Ocean Circulation and Temperature Prediction Model: I. The Pacific*, R-1296-ARPA, 1973, 75 pp.

Alexander, R. C., *An Unfiltered Primitive-equation Model of the Upper Layers of the Pacific Ocean*, P-5247, 1974, 84 pp.

Alexander, R. C., and J. W. Kim, *Diagnostic Model Study of Mixed Layer Depths in the Summer North Pacific*, P-5478, 1975, 29 pp.

Alexander, R. C., and R. L. Mobley, *Monthly Average Sea-Surface Temperatures and Ice-Pack Limits on a 1° Global Grid*, R-1310-ARPA, 1974, 39 pp.

Batten, E. S., *The Atmospheric Response to a Stratospheric Dust Cloud as Simulated by a General Circulation Model*, R-1324-ARPA, 1974, 22 pp.

Bhumralkar, C. M., *Numerical Experiments on the Computation of Ground Surface Temperature in an Atmospheric Circulation Model*, R-1511-ARPA, 1974, 63 pp.

Bhumralkar, C. M., *Parameterization of the Planetary Boundary Layers in Atmospheric General Circulation Models--A Review*, R-1654-ARPA, 1975, 55 pp.

Bhumralkar, C. M., *A Survey of Parameterization Techniques for the Planetary Boundary Layer in Atmospheric Circulation Models*, R-1653-ARPA, 1975, 96 pp.

Bjerknes, J., *Studies in Climate Dynamics for Environmental Security: Large-Scale Ocean/Atmosphere Interaction Resulting from Variable Heat Transfer at the Equator*, RM-6353-ARPA, 1970, 32 pp.

Chervin, R. M., W. L. Gates, and S. H. Schneider, *The Effects of Time Averaging on the Noise Level of Climatological Statistics Generated by Atmospheric General Circulation Models*, P-5237, 1974, 12 pp.

Cooper, D., L. Heiser, R. Mobley, A. Nelson, D. Pass, and M. Seda, *Programming and the Climate Dynamics Project*, P-5269, 1974, 47 pp.

Deirmendjian, D., *Global Turbidity Studies: I. Volcanic Dust Effects--A Critical Survey*, R-886-ARPA, 1971, 73 pp.

Deirmendjian, D., *On Volcanic and Other Turbidity Anomalies*, P-4782, 1972, 52 pp.

Gates, W. L., *Studies in Climate Dynamics for Environmental Security: A Note on the Lateral Eddy Viscosity Due to Transient Rossby Waves in a Barotropic Ocean Model*, RM-6210-ARPA, 1970, 22 pp.

Gates, W. L., *Studies in Climate Dynamics for Environmental Security: Numerical Studies of Transient Planetary Circulations in a Wind-Driven Ocean on the Sphere*, RM-6211-ARPA, 1970, 62 pp.

Gates, W. L., *Analysis of the Mean Forcing Fields Simulated by the Two-level Mintz-Arakawa Atmospheric Model*, R-958-ARPA, 1972, 52 pp.

Gates, W. L., *The January Global Climate Simulated by the Two-level Mintz-Arakawa Model: A Comparison with Observation*, R-1005-ARPA, 1972, 116 pp.

Gates, W. L., *Understanding Climatic Change*, P-5114, 1973, 16 pp.

Gates, W. L., *The Simulation of Arctic Climate with a Global General Circulation Model*, P-5240, 1974, 40 pp.

Gates, W. L., *Numerical Modeling Experiments*, P-5268, 1974, 19 pp.

Gates, W. L., *Numerical Modeling of Climatic Change: A Review of Problems and Prospects*, P-5471, 1974, 27 pp.

Gates, W. L., *The Problem of Climate: A Review for the Nonspecialist*, P-5472, 1975, 17 pp.

Gates, W. L., E. S. Batten, A. B. Kahle, and A. B. Nelson, *A Documentation of the Mintz-Arakawa Two-level Atmospheric General Circulation Model*, R-877-ARPA, 1971, 419 pp.

Gates, W. L., and J. Imbrie, *Climatic Change*, P-5437, 1975, 44 pp.

Gates, W. L., and Y. Mintz, eds.; B. J. Scott, trans., *A Numerical Model of the General Circulation of the Atmosphere Over a Hemisphere, A Translation from* **Trudy, Main Geophysical Observatory, Leningrad, Vol. 256 (1970), pp. 3-44, by M. E. Shvets et al., R-1384-ARPA, 1974, 62 pp.**

Gates, W. L., and A. B. Nelson, *A New Tabulation of the Scripps Topography on a 1° Global Grid. Part I. Terrain Heights,* **R-1276-ARPA, 1973, 140 pp.**

Gates, W. L., and A. B. Nelson, *A New Tabulation of the Scripps Topography on a 1° Global Grid. Part II. Ocean Depths,* **R-1277-ARPA, 1973, 139 pp.**

Gates, W. L., and A. B. Nelson, *A New (Revised) Tabulation of the Scripps Topography on a 1° Global Grid. Part I. Terrain Heights,* **R-1276-ARPA, 1975, 139 pp.**

Gates, W. L., and A. B. Nelson, *A New (Revised) Tabulation of the Scripps Topography on a 1° Global Grid. Part II. Ocean Depths,* **R-1277-1-ARPA, 1975, 139 pp.**

Harslem, E., and S. Landa, *VIEW: A Distributed System for Graphical Analysis of Large Data Bases,* **P-4972, 1973, 33 pp.**

Haurwitz, F., *On Calculating Radiative Fluxes and Temperature Changes in Atmospheres of Arbitrary Structure, Translation from* **Zeitschrift für Geophysik,** *Vol. 8, 1932, pp. 53-64, (R. Mugge and F. Moeler),* **R-1549-ARPA, 1974, 16 pp.**

Haurwitz, F., ed.; D. Lofgren, trans., *The Effect of Reducing the Solar Constant in a Climate Model,* **P-5448, 1975, 9 pp.**

Heiser, L., *Experiences in Designing a Data Retrieval Capability for a Large Data Base,* **P-5113, 1974, 14 pp.**

Hoffman, R., *User's Manual for GLYPLIT: A Program to Translate ILLIAC IV GLYPNIR to IBM 360 PL/1,* **R-857-ARPA, 1972, 74 pp.**

Kahle, A. B., and D. D. Deirmendjian, *The Black Cloud Experiment,* **R-1263-ARPA, 1973, 35 pp.**

Kahle, A. B., and F. Haurwitz, *The Radiation and Heat Budget of the Mintz-Arakawa Model: January,* **R-1318-ARPA, 1973, 71 pp.**

Koenig, L. R., *A Numerical Expe. ment on the Effects of Regional Atmospheric Pollution on Global Climate,* **R-1429-ARPA, 1974, 92 pp.**

Koenig, L. R., and F. W. Murray, *Energy Transformation and Rearrangement Caused by Cumulus Convection,* **P-4832, 1972, 2 pp.**

Koenig, L. R., and F. W. Murray, *Cumulus Cloud Energetics as Revealed in a Numerical Model of Cloud Dynamics,* **R-1613-ARPA, 1975, 76 pp.**

Lamar, J., and R. Stratton, *Chromatic Display of Digital Weather Data*, R-1378-ARPA, 1974, 32 pp.

Laurmann, J., and W. L. Gates, *Statistical Considerations in the Evaluation of Climatic Experiments with General Circulation Models*, P-5503, 1975, 44 pp.

Murray, F. W., and L. R. Koenig, *Numerical Experiments on the Relation Between Microphysics and Dynamics in Cumulus Convection*, R-852-ARPA, 1971, 54 pp.

Pass, D. S., *User's Guide to Auxiliary Programs for the Mintz-Arakawa Atmospheric Model*, R-1046-ARPA, 1974, 73 pp.

Rapp, R. R., and M. Warshaw, *Some Predicted Effects of a Simulated Sahara Lake*, R-1415-ARPA, 1974, 40 pp.

Schutz, C., *Synoptic Performance Characteristics of the Two-level Atmosphere Model*, R-1689-ARPA, 1975, 29 pp.

Schutz, C., and W. L. Gates, *Global Climatic Data for Surface, 800 mb, 400 mb: January*, R-915-ARPA, 1971, 182 pp.

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Schutz, C., and W. L. Gates, *Global Climatic Data for Surface, 800 mb, 400 mb: July*, R-1029-ARPA, 1972, 189 pp.

Schutz, C., and W. L. Gates, *Supplemental Global Climatic Data: January*, R-915/2-ARPA, 1973, 47 pp.

Schutz, C., and W. L. Gates, *Global Climatic Data for Surface, 800 mb, 400 mb: April*, R-1317-ARPA, 1973, 201 pp.

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Semtner, A. J., Jr., *A Model for the Thermodynamic Growth of Sea Ice in Numerical Investigation of Climate*, P-5432, 1975, 33 pp.

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